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Characterization of an Experimental Referee Broadened-Specification (ERBS) Aviation Turbine Fuel and ERBS Fuel Blends

Gary T. Seng
Lewis Research Center
Cleveland, Ohio

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CHARACTERIZATION OF AN EXPERIMENTAL REFEREE BROADENED-SPECIFICATION (ERBS) AVIATION TURBINE FUEL AND ERBS FUEL BLENDS

Gary T. Seng

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

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SUMMARY

Characterization data and comparisons of this data are presented for three individual lots of a research test fuel designated as an Experimental Referee Broadened-Specification (ERBS) aviation turbine fuel. This research fuel, which is a blend of kerosine and hydrotreated catalytic gas oil, is a representation of a kerojet fuel with broadened properties. To lower the hydrogen content of the ERBS fuel, a blending stock, composed of xylene bottoms and hydrotreated catalytic gas oil, was developed and employed to produce two different ERBS fuel blends. The ERBS fuel blends and the blending stock have also been characterized and the results for the blends are compared to those of the original ERBS fuel.

The characterization results indicate that with the exception of the freezing point for ERBS lot 2, which was slightly high, the three lots, produced over a two-year period, met all general fuel requirements. However, although the properties of the fuels were found to be fairly consistent, there were differences in composition. Similarly, all major requirements for the ERBS fuel blends were met or closely approached, and the properties of the blended fuels have been found to generally reflect those expected for the proportions of ERBS fuel and blending stock used in their production.

Fuels characterization studies are continuing through a technical panel of the Coordinating Research Council. Presently, these fuels are being studied as reference fuels in research investigations into the effects of fuel property variations on the performance and durability of jet aircraft combustion systems.

INTRODUCTION

Until recently there has been an abundance of mid-distillates from petroleum available for jet fuel. Future demand for jet fuel is expected to increase at a time when there is severe competition for the available mid-distillates. Changes in property specifications for future fuels could minimize potential curtailments in supplies and might also minimize costs. However, compared to present specification jet fuels, future jet fuels may exhibit any combination of the following property changes: higher aromatic content, higher freezing point, altered fuel volatility, higher viscosity, poorer thermal stability, poorer lubricity, and poorer water separation characteristics. Assessing the effect of changes in jet fuel properties and developing technology to use the fuels will require a large effort in combustor and engine research. Such an effort is in progress at NASA's Lewis Research Center and the Air Force's Wright Aeronautical Laboratories, as well as at a number of other government and industrial research laboratories.

Requirements for an Experimental Referee Broadened-Specification (ERBS) aviation turbine fuel were proposed at a workshop held at Lewis in 1977 to

reflect the potential properties of a future broadened-properties fuel suitable for conducting combustor research (ref. 1). They were written to avoid redundancy, to simplify the logistics involved in supplying the fuel, and to yield sufficiently reproducible combustion characteristics. Later, a technical panel sponsored by the Coordinating Research Council (CRC) recommended several slight modifications to the property requirements. A fuel with the proposed properties was procured and an initial characterization was reported (ref. 2). Two additional lots of the ERBS fuel were produced by the same refinery within 2 years of the original procurement. To simplify the identification process in this report, dashed numbers following the acronym ERBS are used to denote the lot number in chronological order.

For the purpose of studying the effects of lowering the hydrogen content on fuel properties, and component performance and durability, an ERBS fuel blending stock was developed based on CRC technical panel recommendations and blending experiments conducted at Lewis. The blending stock was selected for its hydrogen content, and similarity in volatility to the ERBS fuel. The ERBS fuel and the blending stock were combined to produce two ERBS fuel blends of intermediate hydrogen contents.

This report presents the analytical characterization results of the three lots of ERBS fuel, the two ERBS fuel blends, and the blending stock. In addition to comparisons made between the various fuels, comparisons are made which involve results obtained from outside analytical laboratories.

FUELS BLENDING PROCEDURE

The three lots of ERBS fuel were produced from the kerosine and hydrotreated catalytic gas oil (HCGO) streams of the Marcus Hook refinery of Suntech, Inc. A blend of approximately 65 percent kerosine and 35 percent HCGO by volume was found to meet the ERBS fuel requirements shown in table I. The ERBS fuel blending stock was produced by combining the HCGO stream and a xylene bottoms stream from the same refinery in the approximate proportion of 55 percent to 45 percent by volume, respectively. The ERBS fuel blends are composed of approximately 80 percent ERBS-3 fuel and 20 percent blending stock by volume (actual blend was 79 to 21) for the 12.3 percent hydrogen content fuel, and 60 percent ERBS-3 fuel and 40 percent blending stock for the 11.8 percent hydrogen content fuel. The composition was adjusted to meet the desired hydrogen content.

To minimize the formation of undesirable oxidation products, all fuels are stored under a blanket of gaseous nitrogen. Experience with the first lot indicated that an antioxidant should be added to the fuel, and consequently, an alkylated phenol antioxidant, specified in American Society for Testing and Materials (ASTM) method D-1655, was added to lots 2 and 3.

CHARACTERIZATION RESULTS AND DISCUSSION

Analytical Methodology

Several techniques employed for fuels characterization varied from those originally specified in reference 1 (table I). Sulfur results were obtained using an element-specific nondispersive X-ray fluorescence sulfur analyzer. Kerosine matrix sulfur standards, purchased from a commercial source, were employed in these analyses.

The hydrocarbon compositional analysis was performed by group separation prior to instrumental analyses, rather than gas chromatography-mass

spectrometry (GCMS). The technique employed to obtain the results reported by laboratory 1, a Lewis contractor, involved displacement chromatography using isopropanol. If observed by gas chromatography (GC), isopropanol contamination of the aromatics fractions was removed by water washing the fraction. Following fractionation, GC and mass spectrometric (MS) analyses were performed on the saturates fraction, and MS and nuclear magnetic resonance (NMR) spectrometric analyses were performed on the aromatics fraction. Laboratory 2, an Air Force Wright Aeronautical Laboratories (AFWAL) contractor, employed two methods to obtain the MS results reported. The first method involved fuel separation by ASTM D-2549 (evaporation procedure modified to prevent excessive loss of light ends), followed by MS fraction analysis using ASTM D-2425. The second involved the use of MS method ASTM D-2789 modified to permit the analysis of samples with final boiling points above 211° C (411° F). For comparison purposes, the volume percent data obtained using this technique have been converted to weight percents using average group-type densities.

All kinematic viscosities (ASTM D-445) reported at -23° C (-10° F) were obtained from viscosity temperature curves (ASTM D-341) generated from reference and laboratory data for similar fuels, and using ERBS fuel, blends, and blending stock measurements at 21° C (70° F) and 38° C (100° F).

The broadened-properties fuels are characterized by final boiling points above the limits recommended for group-type determinations by the Fluorescent Indicator Adsorption (FIA) method, as well as for the quantity of naphthalenes by ultraviolet spectroscopy (ASTM D-1840). Furthermore, the relatively large amounts of naphthalenes present in the fuels necessitate more dilution than is specified. As a result, the accuracy of the results reported may be poorer than is normally associated with these methods, and the precision may be poorer than is indicated by the two method descriptions.

Determination of the vapor pressure at 21° C (70° F) was performed in accordance with the equipment and method described by Mottlou (ref. 3).

The Setapoint detector is a recently developed device used to determine the freezing characteristics of mid-distillate fuels. In this technique, the fuel is cooled and forced through a fine mesh screen. As cooling is continued, and the fuel begins to freeze, the pressure drop across the screen increases substantially. As the fuel is warmed, melting occurs, and the pressure drop decreases. Upon reaching a set lower limit (10 mm Hg) of pressure drop, the temperature is recorded. This temperature is referred to as the "Endpoint," and is the value reported in table VI(a).

For all of the fuels studied, jet fuel thermal oxidation tester (JFTOT, ASTM D-3241) breakpoint temperature results were based on a series of at least five trials between 237.5° C and 301.6° C (460° F and 575° F). The breakpoint temperature was defined as a JFTOT maximum spun tube deposit rating (TDR) of 13, or by a test-filter pressure drop of 25 mm Hg. Since the spun rating was the limiting factor in all cases, a least squares fit of the natural logarithm of the spun TDR value versus the inverse of the temperature (in K) was used to obtain each reported breakpoint temperature.

Arc emission spectroscopy was employed to perform the elemental analysis reported. Sample preparation involved sulfuric acid-aided dry ashing in a clean-air facility and muffle furnace (450° C), dissolving the residue in a solution of hydrochloric and nitric acid, and quantitatively spiking silver chloride-impregnated graphite electrodes with the resulting solution. All reagents employed were ultra-high purity grade, and blanks were run in all cases. The accuracy of the analysis is approximately ±50 percent

of the values reported. Those elements that were not detected are reported as "less than" the method detection limits for the sample.

Comparison of ERBS Fuels

Table I presents the NASA Lewis characterization data obtained for the three lots of ERBS fuels. From these data, it appears that the hydrogen contents of the fuels were fairly well controlled. ERBS-2 exhibited a slightly high, but satisfactory value, as a result of an attempt to raise the freezing point by the addition of a small amount of kerosine. Even so, the fuel failed to meet the freezing point requirement and the specification was waived to avoid the possibility of significantly affecting the composition and other properties.

Results for the total aromatics content reported by NASA Lewis for the three lots were found to be within the repeatability of ASTM D-1319 (1.1 vol. %). However, it is interesting to note that aromatics data available from five other laboratories, in combination with that from NASA Lewis, varied over a range of as much as 8 volume percent (ASTM D-1319 reproducibility is 3.7 vol. %). Currently, the CRC Panel on Laboratory Combustion Test Methods (Panel III of the CRC Aviation Group on Combustion Characteristics of the CRC Aviation Committee) is involved in an extensive interlaboratory study to further characterize the ERBS fuel (and blends). The results of this work will yield more detailed information on a number of the analytical techniques employed.

NASA Lewis results for the naphthalenes by ASTM D-1840 were within 0.17 volume percent, somewhat outside the method repeatability value (0.05 vol. %), but reasonable considering the method scope and fuel type. However, as was the case with the total aromatics, it is noteworthy to point out that the naphthalenes data obtained by NASA Lewis and available from three other laboratories covered 4.0 volume percent (0.8 vol.% excluding one laboratory). The stated method reproducibility is 1.1 volume percent. The D-1840 results indicate that naphthalenes compose between 11.8 and 13.2 volume percent (14.0 and 15.7 wt %) of the fuels, with ERBS-2 and ERBS-3 being identical (a slight difference in weight percent). However, the totals of the alkylnaphthalenes and acenaphthenes results from MS analysis (ASTM D-2425), provide different conclusions with values that range between 8.4 weight percent for ERBS-2 and 14.4 weight percent for ERBS-3. Although it is not surprising to observe a conflict in the two methods' results, since inaccuracies could be anticipated in the D-1840 method, it is more difficult to explain a greater D-2425 result for ERBS-3, than is obtained by D-1840. Due to interferences, one would expect the D-1840 results to provide an "upper limit" value.

A comparison of the distillation ranges again indicates some differences. The elevated 90 percent distilled and final boiling points of the ERBS-2 fuel support the higher freezing point observed for this fuel. However, examination of the initial boiling and 10 percent distilled points for ERBS-3 suggests that the observed flash point of this fuel is low. Glass capillary gas chromatography performed by Major D. D. Potter of the AFWAL indicated that the fuel in the drums employed for all analyses were "contaminated" with small quantities (approximately 0.5 wt %) of light ends, primarily toluene. Subsequent flash point analysis of the "uncontaminated" fuel obtained from the same source resulted in a temperature of 66° C (151° F), more in line with the expected results. Further analyses demonstrated

no other significant differences between the "contaminated" and "uncontaminated" fuels.

Viscosity differences at -23° C (-10° F) are observable, but not inconsistent with the observed compositional differences. Obviously, the result at -23° C for ERBS-2 has no true significance since the fuel freezing point is -20° C (-4° F), and it is presented for comparison purposes only. It should be noted that among four laboratories, including NASA Lewis, the available data for the viscosity of any given fuel generally varied significantly, in one case at -23° C by as much as 2.5 cS.

The net heat of combustion of ERBS-1 appears slightly higher than results obtained for the other two fuels. However, it should be pointed out that for all three fuels the reported results are approximately one percent lower than the average of values available from two other laboratories. Currently, there is no explanation for the observed differences.

It was originally thought that the rather high lead content of ERBS-1 contributed to the low breakpoint temperature. However, an examination of the elemental analysis data shows that a similar content occurs in all three lots. If this is true, the lower thermal stability was most likely due to the fact that ERBS-1 contained no antioxidant, and was not immediately characterized by ASTM D-3241 upon arrival.

Table II(a) presents the group-type results obtained by laboratory 1 in weight percent prior to further analyses. In terms of actual group-type totals, these data are somewhat misleading due to cross contamination between the saturates and aromatics fractions as is shown in II(c). Disregarding the fraction reported as lost, the results obtained for the aromatics fraction by MS are 32.1, 29.3, and 28.9 weight percent for ERBS fuels one, two and three, respectively. However, with the fuels being of similar composition, and undergoing identical separations, consideration of the fractions lost would tend to suggest that larger differences may actually exist between the fuels.

Differences are also apparent in the quantities of normal paraffins found in the fuels, which are presented in table II(b), and in the distribution of paraffins and aromatics among the various compound classes, as is shown in table II(c). Relative to the total of the group-type results for each fuel, paraffins, condensed dicycloparaffins, and condensed tricycloparaffins are highest in ERBS-3 and noncondensed cycloparaffins the lowest. Similarly, ERBS-3 exhibits the highest relative dicyclic and tricyclic aromatics quantities, and the lowest monoaromatics. However, it should be noted that the results for ERBS-3, reported in a later section by laboratory 2, disagree with several of these findings. ERBS-2 is shown to exhibit the lowest relative amounts of naphthalenes.

NMR analysis of the aromatics fractions of the fuels, presented in table II(d) primarily demonstrates differences in the average molecular weights (and molecular formulas), the average number of aromatic ring carbons per molecule (and rings per molecule), the naphthenic carbon content, and the quantities of mono-, di-, and tricyclic aromatics. The higher ERBS-3 molecular weight and aromatic ring carbon results support the MS findings, while the results of the aromatic classes (mono-, di-, and tricyclic) disagree, both in the magnitude and relative order among the three fuels. With the amount of data presently available, it is difficult to make any judgements concerning the validity of the data from the two methods. However, the NMR method is not a standard method which has undergone the extensive testing procedures associated with the ASTM D-2425 MS method.

The results of elemental analyses of the fuels, shown in table III, are reasonable for mid-distillate fuels of this type with only a few exceptions. Iron appears high in ERBS-3 and zinc in ERBS-2. Both are elements that might easily be introduced during transport, storage, or analysis. Of particular interest are the relatively high lead contents observed for all three fuels and verified in ERBS-1 by atomic absorption spectroscopy. These findings are not easily explained.

The results of the water separation index, modified (WSIM - ASTM D-2550), the electrical conductivity (ASTM D-3114) and the fuel charging tendency (ministatic tester) are presented in table IV for ERBS-2. The data were provided by M. Lieberman of the Exxon Research and Engineering Co., as a portion of some in-depth characterization studies. The ERBS-2 fuel exhibits a lower WSIM, higher electrical conductivity and higher charging tendency when compared to a typical, untreated Jet A. Clay-treating returns the fuel to values more typical of Jet A, and comparable to the clay-treated Jet A sample, although some differences are still observed.

Comparison of ERBS Fuel and ERBS Fuel Blends

The requirements for the ERBS-3 fuel, the blending stock, and the ERBS fuel blends, are shown in table V. Note that for these fuels two additional requirements (naphthalenes and total aromatics) were imposed, in a further attempt to improve fuel reproducibility. With the exceptions of the naphthalenes content for ERBS-3 and the blends as determined by ASTM D-1840, and the flash point of the blending stock, the requirements were met (table VI). However, MS analyses (table VII) contradict the D-1840 results and indicate that the naphthalenes content requirement for each of the blends was met as well.

Detailed characterization data for the fuels and blending stock are presented in tables VI and VII. All data designated as provided by laboratory 2 or marked with an asterisk, were supplied by Major D. D. Potter of the AFWAL following their independent, extensive in-house and contractor (laboratory 2) studies of the fuels and blending stock.

From table VI, it is apparent that the properties of the two blended fuels are about what would be expected from the proportions and properties of ERBS-3 and the blending stock.
As was found to be true for the ERBS fuels, interlaboratory results for the FIA (ASTM D-1319), naphthalenes content (ASTM D-1840) and viscosity (ASTM D-445) exceeded the stated reproducibility of the methods, and the net heats of combustion (ASTM D-2382) reported, again appear somewhat low in comparison with two other laboratories.

Figures 1 and 2 are ASTM D-86, and D-2887 distillation curves, respectively, plotted from the data presented in table VI(b). The curves appear reasonable for fuels of this type. The unusual simulated distillation curve for the blending stock, also reflected in the ERBS-3 11.8% H fuel, is due to the blending of the light xylene bottoms stream and the higher-boiling HCGO stream.

Group-type results obtained for fractions employed in GC, MS and NMR analyses are shown in table VII(a). Although laboratory 2, employing ASTM D-2549, reported no loss data specifically for these fuels, their experience has been that for fuels of this type, any loss is within the method repeatability, i.e., approximately 1.4 weight percent. Laboratory 2 did report a breakthrough of 6.2 % of the alkylbenzenes into the paraffin fraction for the blending stock, which was totaled with the alkylbenzene group in the MS

results (table VII(d)), but not included in the separation data as a part of the aromatics fraction (table VII(a)). Only 0.3 weight percent of aromatics breakthrough was observed in the paraffin fractions of the other fuels. Using the blending information presented earlier (converted to wt %), and rough conversions of FIA and high performance liquid chromatography (HPLC) results (table VI(a)) to weight percent, it appears as if the ERBS-3 aromatics result from laboratory 2 (table VII(a)) is high. Similarly, the blending stock aromatics result appears low (including the 6.2 wt % alkylbenzene breakthrough). Furthermore, although the results for the blends approximate the HPLC and FIA data, they are inconsistent with the values calculated using the blending equations and the ERBS-3 and blending stock results reported. Laboratory 1 results (table VII(a)) are more consistent with the blending information and volume percent data (table VI(a)).

For the saturate class analysis, MS (ASTM D-2425) results (table VII(c)) for both laboratories expressed as a percentage of their original saturate group-type separation values (table VII(a)) demonstrate that the two laboratories do not differ as much as the absolute magnitudes of the data might indicate by examination of the MS data alone. The results appear to differ the most for the blending stock. The modified ASTM D-2789 data (converted to wt % using the densities presented in table VII(f)) result in the highest total saturates quantities of the three MS reports with lower relative paraffins and noncondensed cycloparaffins, but much higher condensed dicycloparaffins (table VII(c)).

As table VII(d) shows, the distribution of the aromatics fraction among the various classes is substantially different for the two laboratories. Laboratory 1 reports relatively low monoaromatics and high di and triaromatics. Although from physical property data and NMR data (table VII(e)), ERBS-3 exhibits a slightly higher aromatics fraction molecular weight than the other two ERBS fuels, it is uncertain if the laboratory 1 data correctly reflects this difference. One indication of possible inconsistency is the fact that the blending information applied to the laboratory 1 MS data predicts substantially higher alkylbenzene levels than were reported for the two blended fuels. Another stems from the fact that the blending stock is composed of approximately 45 volume percent xylene bottoms, which in itself is virtually 100 percent alkylbenzenes. Therefore, laboratory 1 results for at least the alkylbenzene class appear questionable.

As was found for the three lots of ERBS fuels, the NMR results for the aromatic classes (mono-, di and tri-) of table VII(e) differ substantially from those reported using either ASTM D-2425 MS analysis of the aromatics fraction. Based on blending information, and previous discussions, it is obvious that a substantial portion of these data are questionable.

With the exception of lead, which is observed in all three fuels and the blending stock in relatively high amounts, the only elements found which exceed typical limits are the magnesium, silicon and zinc results reported for the blending stock (table VIII). Although a clean-air facility is employed during the analytical sample preparation process, the most likely reason for these elevated values is laboratory airborne particulate contamination of the sample.

CONCLUDING REMARKS

The ERBS aviation turbine fuel, originally outlined at a Lewis workshop in 1977, has been procured from the Marcus Hook Refinery of Suntech, Inc. in three different lots over a 2-year period. With the exception of the freez-

ing point in ERBS-2 which was slightly high, characterization results indicate that the three fuels met all general requirements. Report items are sufficiently comparable to conclude that the ERBS fuel can be blended at one refinery over a moderate time period with reasonable success in reproducibility, despite changes in the crude source. However, although the properties of the fuels were found to be fairly consistent, there were differences in composition.

An ERBS fuel blending stock was identified, characterized, and employed to prepare two ERBS-3 fuel blends at hydrogen contents of 12.3 and 11.8 weight percent. With the exceptions of a slightly low flash point for the blending stock, and low naphthalenes contents by ASTM D-1840 for the blends, the blends and blending stock met the requirements. However, MS results contradict the D-1840 results and conclude that the naphthalenes requirements were met as well. A comparison of the ERBS-3 fuel and the two blended fuels indicates that the properties of the blended fuels generally reflect those expected for the ERBS fuel and blending stock proportions required to attain the proper hydrogen contents.

The relatively large range of interlaboratory results observed for such techniques as mass spectroscopy, naphthalenes by D-1840 and group type analysis by D-1319, among others, emphasize the need for more analytical methods development work in the area of broadened-properties fuels, and for an expanded effort to characterize these fuels. The characterization work is presently in progress and is being conducted through a CRC technical panel. The results of this study should improve our knowledge of the precision and accuracy of a number of classical and modern methods including those presented in this report.

REFERENCES

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TABLE I. - ERBS FUELS REQUIREMENTS AN CHARACTERIZATION RESULTS

Property	ERBS-1	ERBS-2	ERBS-3	Requirements	Test method
Composition:					
Hydrogen, wt %	12.86	12.94	12.85	12.8±0.2	ASTM D-3701
Aromatics, vol. %[e]	28.8	29.3	28.8	Report	ASTM D-1319
Sulfur, mercaptan, wt %	0.0005	<0.0003	<0.0003	0.003 max.	ASTM D-3227
Sulfur, total, wt %	0.068	0.074	0.042	0.3 max.	ASTM D-1266
Nitrogen, total, wt %	0.0054	0.0084	0.0043	Report	ASTM D-3431
Naphthalenes, vol. % (wt %)[e]	13.2 (15.7)	11.8 (14.2)	11.8 (14.0)	Report	ASTM D-1840
Hydrocarbon compositional analysis	Table II	Table II	Table II	Report	GCMS[a]
Volatility:					
Distillation temperature, °C (°F)					
Initial boiling point	162 (324)	169 (335)	178 (352)	Report	ASTM D-86
10 Percent	188 (370)	187 (368)	201 (393)	204 (400) max.	
50 Percent	215 (419)	212 (414)	226 (439)	Report	
90 Percent	279 (534)	293 (560)	286 (546)	260 (500) min.	
Final boiling point	328 (622)	342 (647)	324 (615)	Report	
Residue, percent	1.2	1.0	1.0	Report	
Loss, percent	0.3	0.4	0.5	Report	
Flash point, °C (°F)	60 (140)	61 (142)	60 (140)	[b]38 (100) min.	ASTM D-56
Gravity, API (15° C)	37.1	38.2	36.6	Report	ASTM D-287
Gravity, specific (15°/15° C)	0.8381	0.8338	0.8418	Report	ASTM D-1298
Fluidity:					
Freezing point, °C (°F)	-29 (-20)	[c]-20 (-4)	-26 (-15)	[b]-23 (-10) max.	ASTM D-2386
Viscosity, cS, -23° C (-10° F)	7.2	[d]7.9	9.2	12 max.	ASTM D-445
-21° C (70° F)	2.14	2.24	2.52	---------------	
Net heat of comb., kJ/kg (BTU/lb)	42,200(18,180)	42,066(18,120)	42,020(18,100)	Report	ASTM D-2382
Thermal stability:					
JFTOT, Breakpt. Temp., °C (°F) (TDR, 13; or ΔP, 25 mm Hg)	256(492)	274(525)	277(531)	238(460) min.	ASTM D-3241

[a]For this paper, the method employed was not GCMS - See Analytical Methodology Section.
[b]Modified from that in ref. 1.
[c]Freezing point specification waived-see Characterization Results and Discussion Section.
[d]Extrapolated-fuel freezes at -20° C.
[e]The ERBS fuel properties and composition are outside of the limits specified by the respective methods - See Analytical Methodology Section.

TABLE II. - ERBS FUELS HYDROCARBON COMPOSITIONAL ANALYSIS RESULTS

(a) Group-type analysis results by modified FIA, ASTM D-1319, in wt % of sample

Group type	ERBS-1	ERBS-2	ERBS-3
Saturates	60.8	63.4	67.9
Olefins	0.0	0.0	0.4
Aromatics	34.3	32.6	30.0
Loss	4.9	4.0	1.7

(b) Normal paraffins by gas chromatography, in wt % of sample

Carbon number	ERBS-1	ERBS-2	ERBS-3
C_9	1.1	0.4	0.6
C_{10}	3.4	2.3	2.0
C_{11}	4.4	4.4	4.7
C_{12}	4.0	5.0	6.4
C_{13}	2.7	2.5	5.0
C_{14}	1.4	0.7	2.2
C_{15}	1.2	0.5	1.1
C_{16}	1.0	0.5	0.9
C_{17}	0.9	0.5	0.8
C_{18}	0.6	0.4	0.5
C_{19}	0.3	0.3	0.3
C_{20}	0.2	0.2	0.1
Totals	21.2	17.7	24.6

TABLE II. - ERBS FUELS HYDROCARBON COMPOSITIONAL ANALYSIS RESULTS (CONTINUED)

(c) Mass spectrometric group analysis by modified ASTM D-2425, in wt % of sample

Saturates group	ERBS-1	ERBS-2	ERBS-3	Aromatics group	ERBS-1	ERBS-2	ERBS-3
Paraffins	37.1	38.7	44.9	Paraffins	0.6	1.1	0.5
Noncondensed cycloparaffins	17.7	18.0	12.3	Cycloparaffins	1.9	2.4	0.6
				Alkylbenzenes	10.8	9.9	3.3
Condensed dicycloparaffins	4.7	5.3	8.8	Indans and tetralins	5.6	6.5	4.1
				Indenes and $C_NH_{(2N - 10)}$	0.3	0.7	1.6
Condensed tricycloparaffins	1.0	1.2	2.0	Naphthalene	0.0	0.0	0.1
Alkybenzenes	0.3	0.2	0.0	Alkylnaphthalenes	9.5	5.7	11.0
				Benzothiophenes	0.4	0.0	0.3
				Acenaphthenes	2.6	2.7	3.2
				Fluorenes - Acenaphthylenes	1.3	1.6	1.9
				Tricyclic Aromatics	1.4	2.0	3.4

(d) Nuclear magnetic resonance analysis of aromatics fraction

Information[a]	ERBS-1	ERBS-2	ERBS-3
Average molecular wt	190.2	193.6	205.0
Average molecular formula	$C_{14.5}H_{16.3}$	$C_{14.7}H_{17.0}$	$C_{15.6}H_{17.3}$
Aromaticity	0.62	0.60	0.62
Aromatic rings per molecule	1.7	1.7	1.9
Aromatic ring carbons per molecule	8.9	8.8	9.7
Saturate carbon content, wt %	38.2	39.8	37.8
Alkyl substituents per molecule	3.1	3.1	3.1
Carbons per alkyl substituent	1.8	1.9	1.9
Carbon-hydrogen ratio of alkyl groups	5.55	5.56	5.64
Naphthenic carbon content, wt %	6.7	8.8	9.8
Naphthene rings per molecule	0.3	0.4	0.4
Naphthene rings per substituent	0.1	0.1	0.1
Nonbridge aromatic ring carbon content, wt %	51.7	50.5	50.3
Nonbridge aromatic carbons per molecule	7.5	7.4	7.9
Substitution of nonbridge aromatic carbons, wt %	43.2	42.7	40.6
Monoaromatic content, wt %	38.3	36.3	13.8
Diaromatic content, wt %	49.8	56.1	79.6
Triaromatic content, wt %	11.9	7.6	6.6

[a]All weight percent results are expressed as a percentage of the aromatics fraction.

TABLE III. - ERBS FUEL ELEMENTAL ANALYSIS BY ARC EMISSION SPECTROSCOPY

Element	Concentration, ppm by wt		
	ERBS-1	ERBS-2	ERBS-3
Al	0.0005	-	0.003
As	<.003	-	<.008
Ca	.001	0.007	.015
Cd	<.0004	-	<.002
Cr	<.0001	.0004	.0008
Cu	.01	.003	.0015
Fe	.002	.02	.1
K	-	<.04	<.008
Mg	.0002	.0015	.002
Mn	<.0003	.007	.002
Mo	.001	<.0005	.002
Na	.003	<.008	.008
Ni	.002	.0004	.001
P	<.01	-	<.04
Pb	([a]0.12)0.08	.2	.2
Si	.02	.0065	.006
Sn	.001	<.0008	<.0008
Ti	<.0003	.00035	<.00003
V	.0008	<.0001	<.0001
Zn	.001	.09	.01

[a]Value determined by atomic absorption spectroscopy.

TABLE IV. - COMPARISON OF ERBS FUEL (LOT 2) AND JET A (CLAY-TREATED) WATER SEPARATION AND ELECTRICAL PROPERTIES

Fuel condition	WSIM ASTM D-3602 Δ Transmission	Elect. conductivity[a] ASTM D-3114 pS/M	Ministatic charge[b] $\mu C/M^3$
Dried ERBS (26 ppm H_2O)	-	157	2,920
H_2O Saturated ERBS (112 ppm H_2O)	0	98	2,255
H_2O Saturated ERBS After Clay Treatment	97	2.3	130
H_2O Saturated Jet A After Clay Treatment	98	0.5	14
H_2O Saturated, Clay Treated ERBS + 1ppm ASA-3[c]	65	473	-518
H_2O Saturated, Clay Treated Jet A + 1ppm ASA-3[c]	74	445	479

[a]Results obtained at 25° C.
[b]Using C-709 facet filter.
[c]Anti-static Additive 3.

TABLE V. - ERBS FUEL (LOT 3), ERBS FUEL BLENDS, AND BLENDING STOCK REQUIREMENTS

Property	ERBS-3	ERBS-3 12.3% H Blend	ERBS-3 11.8% H Blend	Blending stock	Test method
Composition:					
Hydrogen, wt %	12.8 ± 0.2	12.3 ± 0.2	11.8 ± 0.2	10.2 ± 0.2	ASTM D-3701
Aromatics, vol. %	28 min.[a]	38 min.	48 min.	81 min.	ASTM D-1319
Sulfur, mercaptan, wt %	0.003 max.	Report	Report	Report	ASTM D-3227
Sulfur, total, wt %	0.3 max.	Report	Report	Report	ASTM D-1266
Naphthalenes, vol. %	13 min.[a]	14 min.	15 min.	18 min.	ASTM D-1840
Volatility:					
Distillation temperature, °C (°F)					
Initial boiling point	Report	Report	Report	Report	ASTM D-86
10 Percent	149-204(300-400)	Report	Report	143-163(290-325)	
50 Percent	Report	Report	Report	Report	
90 Percent	260-316(500-600)	Report	Report	288-316(550-600)	
Final boiling point	Report	Report	Report	Report	
Residue, percent	Report	Report	Report	Report	
Loss, percent	Report	Report	Report	Report	
Flash point, °C (°F)	38(100)min.	38(100)min.	38(100)min.	38(100)min.	ASTM D-56
Gravity, API (15° C)	Report	Report	Report	Report	ASTM D-287
Gravity, specific (15°/15° C)	Report	Report	Report	Report	ASTM D-1298
Fluidity:					
Freezing point, °C (°F)	-23 (-10)max.	Report	Report	Report	ASTM D-2386
Viscosity, cS, at -23° C (-10° F)	12 max.	Report	Report	Report	ASTM D-445
Thermal Stability:					
JFTOT - Temp., °C (°F) for TDR, 13 or ΔP, 25 mm Hg	238(460)min.	Report	Report	Report	ASTM D-3241

[a]Requirement added to lot 3 only.

TABLE VI. - ERBS FUEL, ERBS FUEL BLENDS, AND BLENDING STOCK CHARACTERIZATION RESULTS

(a) Characterization results (not including distillation data)

Property classification	Property	ERBS-3	ERBS-3 12.3% H Blend	ERBS-3 11.8% H Blend	Blending stock	Test method
Appearance	*Saybolt Color	Below -16	Below -16	Below -16	Below -16	ASTM D-156
Composition	Hydrogen, wt %	12.85	12.30	11.78	10.26	ASTM D-3701
	Carbon, wt %	86.36	87.52	87.46	89.32	Microcombustion
	Sulfur, wt %	0.042	0.051	0.058	0.088	S specific NDXRF
	*Sulfur, Mercaptan, wt %	0.0003	0.0003	0.0004	0.0003	ASTM D-1219
	Nitrogen, wt %	0.0043	0.0048	0.0060	0.0077	ASTM D-3431
	Aromatics, vol. % - FIA[a], HPLC	28.8, 26.5	39.6, 37.7	49.6, 47.3	83.4, 80.1	ASTM D-1319
	Saturates, vol. % - FIA[a], HPLC	71.8, 73.5	60.8, 62.3	50.2, 52.7	17.7, 19.9	and
	Olefins, Vol. % - FIA[a], HPLC	0.7, 0.3	0.5, 0.3	0.7, 0.3	0.8, 0.3	HPLC
	Naphthalenes, vol. % (wt %)[a]	11.76 (13.97)	13.41 (15.72)	14.74 (17.06)	20.51 (22.89)	ASTM D-1840
Volatility	Flash Point, °C (°F)	60 (140)	53 (127)	48 (118)	36 (96)	ASTM D-56
	Flash Point, °C (°F)	79 (174)	69 (156)	64 (148)	48 (118)	ASTM D-92
	*Vapor Pressure, mm Hg, 21° C	12.5	8.0	14.5	18.0	Ref. 3
	Gravity, API, 15° C	36.6	34.3	32.3	26.4	ASTM D-287
	Gravity, Specific (15° /15° C)	0.8418	0.8532	0.8639	0.8961	ASTM D-1298
	Distillation Temp.	Table VI(b)	Table VI(b)	Table VI(b)	Table VI(b)	ASTM D-86, D-2887
Fluidity	Freezing Point, °C (°F)	-26 (-15)	-25 (-14)	-24 (-11)	-22 (-8)	ASTM D-2386
	Setapoint Fr. Pt. Detector, Endpoint, °C (°F)	-35.0 (-31.0)	-37.3 (-35.1)	-35.7 (-32.3)	-33.5 (-28.3)	Setapoint Fr. Pt. Detector
	Viscosity, cS, -23° C (-10° F)	9.2	7.9	7.0	4.6	ASTM D-445
	* -20° C (-4° F)	8.19	6.92	6.04	4.63	
	* 0° C (32° F)	4.19	3.67	3.30	2.65	
	* 40° C (104° F)	1.79	1.63	1.51	1.29	
Combustion	Net Heat of Comb., kJ/kg(Btu/lb)	42,020(18,100)	41,640(17,940)	41,200(17,750)	40,230(17,330)	ASTM D-2382
	Smoke Point	14	11	9	5	ASTM D-1322
	Luminometer No.	25	22	13	5	ASTM D-1740
Stability	JFTOT, Breakpt.Temp., °C (°F)	277 (531)	276 (530)	266 (511)	259 (499)	ASTM D-3241
Contaminants	*Existent Gum, mg/100 ml	2.0	1.6	2.0	1.8	ASTM D-381
	*Particulates, mg/l	2.5	0.5	2.1	2.3	ASTM D-2276
	Water React. Vol. Change, ml	0.0	0.0	0.0	0.5	ASTM D-1094
	Water Reaction Interface Rating	2	1	1	4	ASTM D-1094
Additives	Antioxidant, 24.0 mg/l	75% min. 2,6-ditertiary-butyl phenol plus 25% max. tertiary and tritertiary butyl phenols				ASTM D-1655
Other	*Surface Tension, dynes/cm, 21° C	27.7	28.3	28.6	30.0	Capillary Rise
	Ramsbottom C on 10% Residue	0.11	0.095	0.092	0.14	ASTM D-524
	Refractive Index, 27° C	1.4700	1.4782	1.4866	1.5118	ASTM D-1218

*Analyses performed at the AFWAL or laboratory 2.

[a]The fuel properties and composition are outside of the limits specified by the respective methods - see Analytical Methodology Section.

TABLE VI. - ERBS FUEL, ERBS FUEL BLENDS, AND BLENDING STOCK CHARACTERIZATION RESULTS (CONTINUED)

(b) Distillation data

Volume % Distilled	ASTM D-86, Distillation temperature, °C (°F)				*ASTM D-2887, Simulated distillation temperature, °C (°F)			
	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blending stock	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blending Stock
IBP	178 (352)	154 (310)	145 (293)	133 (272)	134 (273)	110 (230)	109 (228)	108 (226)
5	196 (384)	174 (345)	161 (321)	144 (292)	172 (342)	142 (288)	137 (279)	135 (275)
10	201 (393)	183 (361)	168 (335)	148 (299)	184 (363)	166 (331)	144 (291)	137 (279)
15	--- ---	--- ---	--- ---	--- ---	194 (381)	177 (351)	165 (329)	138 (280)
20	207 (405)	196 (384)	183 (361)	155 (311)	198 (388)	190 (374)	173 (343)	140 (284)
25	--- ---	--- ---	--- ---	--- ---	205 (401)	197 (387)	188 (370)	144 (291)
30	212 (414)	207 (405)	197 (387)	167 (332)	212 (414)	206 (403)	197 (387)	161 (322)
35	--- ---	--- ---	--- ---	--- ---	216 (421)	214 (417)	208 (406)	167 (333)
40	220 (428)	217 (422)	211 (412)	185 (365)	220 (428)	218 (424)	216 (421)	169 (336)
45	--- ---	--- ---	--- ---	--- ---	226 (440)	225 (437)	224 (435)	194 (381)
50	226 (439)	227 (441)	226 (438)	218 (424)	231 (448)	230 (446)	230 (446)	227 (441)
55	--- ---	--- ---	--- ---	--- ---	235 (455)	235 (455)	236 (457)	242 (468)
60	235 (455)	232 (459)	238 (460)	254 (489)	240 (464)	243 (469)	245 (473)	248 (478)
65	--- ---	--- ---	--- ---	--- ---	247 (477)	249 (480)	250 (482)	253 (487)
70	244 (472)	248 (478)	252 (485)	266 (511)	252 (486)	253 (487)	256 (493)	264 (507)
75	--- ---	--- ---	--- ---	--- ---	261 (502)	264 (507)	267 (513)	271 (520)
80	260 (500)	263 (505)	266 (511)	278 (532)	270 (518)	273 (523)	276 (529)	281 (538)
85	--- ---	--- ---	--- ---	--- ---	284 (543)	286 (547)	289 (552)	294 (561)
90	286 (546)	288 (550)	289 (552)	299 (570)	300 (572)	302 (576)	304 (579)	308 (586)
95	--- ---	--- ---	--- ---	--- ---	322 (612)	324 (615)	325 (617)	328 (622)
FBP	324 (615)	327 (620)	326 (618)	333 (632)	364 (687)	365 (689)	367 (693)	368 (694)
Residue,%	1.0	1.0	1.0	1.0				
Loss,%	0.5	0.5	1.0	1.0	NOT APPLICABLE			

*Data provided by the AFWAL.

TABLE VII. - ERBS FUEL, ERBS FUEL BLENDS, AND BLENDING STOCK HYDROCARBON COMPOSITIONAL ANALYSIS RESULTS

(a) Group-type analysis results, in wt % of sample

Group Type	Laboratory 1 modified FIA, ASTM D-1319				Laboratory 2 modified ASTM D-2549			
	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blending stock	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blending stock
Saturates	67.9	57.2	46.8	17.1	62.2	60.2	53.5	29.8
Olefins	0.4	0.4	0.4	0.4	-	-	-	-
Aromatics	30.0	41.5	51.6	81.4	37.8	39.8	46.6	70.2
Loss	1.7	0.9	1.2	1.1	None Reported			

(b) Normal paraffins by gas chromatography, in wt % of sample

Carbon number	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blending stock
C_8	0.3	0.6	1.2	-
C_9	0.6	0.6	2.1	0.4
C_{10}	2.0	2.4	2.5	0.8
C_{11}	4.7	3.9	2.5	0.1
C_{12}	6.4	4.6	3.3	0.2
C_{13}	5.0	3.5	2.7	0.5
C_{14}	2.2	1.7	1.4	1.1
C_{15}	1.1	1.0	0.9	1.2
C_{16}	0.9	0.8	0.8	1.0
C_{17}	0.8	0.7	0.7	0.9
C_{18}	0.5	0.5	0.5	0.6
C_{19}	0.3	0.3	0.4	0.4
C_{20}	0.1	0.2	0.2	0.2
Totals	24.9	20.8	19.2	7.4

TABLE VII. - ERBS FUEL, ERBS FUEL BLENDS, AND BLENDING STOCK HYDROCARBON COMPOSITIONAL ANALYSIS RESULTS (CONTINUED)

(c) Mass spectrometric saturates group analysis, in wt % of sample

Saturates group	Laboratory 1				Laboratory 2							
	Modified FIA fractionation, MS by modified ASTM D-2425				Modified ASTM D-2549 fractionation, MS by ASTM D-2425				MS by modified ASTM D-2789			
	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blend. stock	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blend. stock	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blend. stock
Paraffins	44.9	36.5	30.5	9.5	38.7	37.7	30.0	17.0	43.4	37.4	32.9	16.6
Noncondensed cycloparaffins. .	12.3	12.4	10.9	2.2	14.6	14.1	10.3	3.7	27.5	22.9	19.5	6.4
Condensed dicycloparaffins	8.8	6.8	4.7	3.0	7.2	6.9	5.3	2.9	2.8	2.7	2.2	1.0
Condensed tricycloparaffins	2.0	1.5	0.7	1.3	2.1	1.9	1.5	0.9	-	-	-	-
Alkylbenzenes . . .	0.0	0.0	0.0	1.2	0.3	0.3	0.3	6.2	-	-	-	-

TABLE VII. - ERBS FUEL, ERBS FUEL BLENDS, AND BLENDING STOCK HYDROCARBON COMPOSITIONAL ANALYSIS RESULTS (CONTINUED)

(d) Mass spectrometric aromatics group analysis, in wt. % of sample

Aromatics group	Laboratory 1				Laboratory 2							
	Modified FIA fractionation, MS by modified ASTM D-2425				Modified ASTM D-2549 fractionation, MS by ASTM D-2425				MS by modified ASTM D-2789			
	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blend. stock	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blend. stock	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blend. stock
Paraffins	0.5	0.4	0.9	0.0	----	----	----	----	---	----	----	----
Cycloparaffins . .	0.6	0.6	0.7	0.0	----	----	----	----	---	----	----	----
Alkylbenzenes . . .	3.3	4.4	6.1	24.2	9.8	13.0	21.6	[a]35.3	8.0	17.9	26.3	54.5
Indans and tetralins	4.1	5.2	6.5	6.2	7.9	7.0	7.1	5.8	9.4	8.8	7.6	5.2
Indenes and $C_NH_{(2N-10)}$	1.6	1.8	2.0	2.1	1.2	0.5	0.5	0.0	---	----	----	----
Naphthalene	0.1	0.1	0.1	0.2	0.0	0.0	0.0	0.0	---	----	----	----
Alkylnaphthalenes .	11.0	16.8	22.0	36.5	12.2	12.4	15.9	22.3	8.9	10.3	11.5	16.3
Benzothiophenes . .	0.3	0.0	0.1	0.0	----	----	----	----	---	----	----	----
Acenaphthenes . . .	3.2	4.2	4.3	2.0	3.0	3.1	3.6	5.3	---	----	----	----
Fluorenes-Acenaphthylenes .	1.9	2.9	3.5	3.8	2.0	2.1	2.6	3.9	---	----	----	----
Tricyclic Aromatics	3.4	5.2	5.3	6.3	1.3	1.3	1.6	2.9	---	----	----	----

[a]Includes 6.2 wt % of alkylbenzenes found in saturates fraction.

TABLE VII. - ERBS FUEL, ERBS FUEL BLENDS, AND BLENDING STOCK HYDROCARBON COMPOSITIONAL ANALYSIS RESULTS (CONTINUED)

(e) Nuclear magnetic resonance analysis of aromatics fraction

Information[b]	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blending stock
Average molecular weight	205.0	199.2	189.9	182.9
Average molecular formula	$C_{15.6}H_{17.3}$	$C_{15.3}H_{15.7}$	$C_{14.6}H_{14.8}$	$C_{14.1}H_{13.2}$
Aromaticity	0.62	0.66	0.67	0.71
Aromatic rings per molecule	1.9	2.0	2.0	2.0
Aromatic ring carbons per molecule	9.7	10.1	9.8	10.0
Saturate carbon content, wt %	37.8	33.6	32.6	28.9
Alkyl substituents per molecule	3.1	3.2	3.1	3.3
Carbons per alkyl substituent	1.9	1.6	1.5	1.2
Carbon-hydrogen ratio of alkyl groups	5.64	5.74	5.72	5.81
Naphthenic carbon content, wt %	9.8	6.9	7.2	2.9
Naphthene rings per molecule	0.4	0.3	0.3	0.1
Naphthene rings per substituent	0.1	0.1	0.1	0.0
Nonbridge aromatic ring carbon content, wt %	50.3	52.8	54.3	56.8
Nonbridge aromatic carbons per molecule	7.9	8.1	7.9	8.0
Substitution of nonbridge aromatic carbons,wt %	40.6	39.9	40.2	41.4
Monoaromatic content, wt %	13.8	10.7	11.1	5.6
Diaromatic content, wt %	79.6	75.1	82.4	87.9
Triaromatic content, wt %	6.6	14.2	6.6	6.5

[b]All weight percent results are expressed as a percentage of the aromatics fraction.

(f) Average densities employed by laboratory 2 to convert ASTM D-2789 volume percent data to weight percent

Group type	Density
Paraffins	0.75
Monocycloparaffins	0.81
Dicycloparaffins	0.81
Alkylbenzenes	0.87
Indans and Tetralins	0.93
Alkylnaphthalenes	1.00

TABLE VIII. - ERBS FUEL, ERBS FUEL BLENDS AND BLENDING STOCK ELEMENTAL ANALYSIS BY ARC EMISSION SPECTROSCOPY

Element	Concentration, ppm by wt			
	ERBS-3	ERBS-3 12.3% H	ERBS-3 11.8% H	Blending stock
Al	0.003	0.002	0.011	0.01
As	<.008	<.008	<.008	<.008
Ca	.015	.03	.01	.04
Cd	<.002	<.002	<.002	<.002
Cr	.0008	.0025	.0015	.0012
Cu	.0015	.0025	.0025	.04
Fe	.1	.055	.055	.03
K	<.008	<.008	<.008	<.008
Mg	.002	.002	.0015	.15
Mn	.002	.001	.0004	0007
Mo	.002	.005	.00008	<.00003
Na	.008	.0008	<.0001	<.0001
Ni	.001	.0025	<.0004	.0007
P	<.04	<.04	<.04	<.04
Pb	.2	.2	.05	.2
Si	.006	.006	.0017	.1
Sn	<.0008	<.0008	<.0008	<.0008
Ti	<.00003	<.00003	<.00003	.004
V	<.0001	<.0001	<.0001	<.0001
Zn	.01	.01	<.002	.35

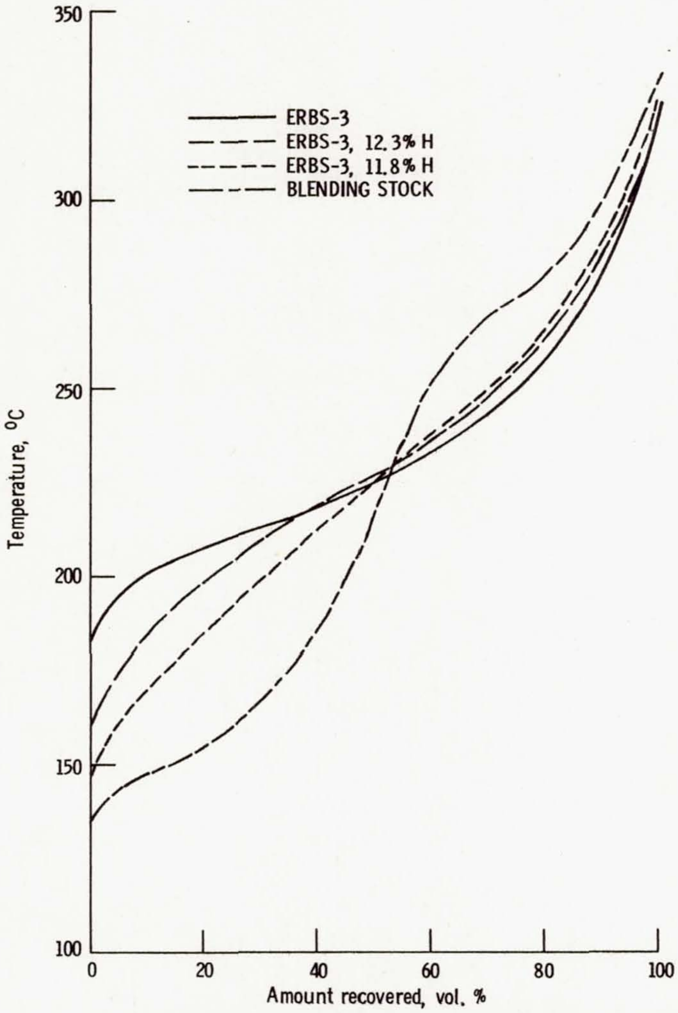

Figure 1. - ASTM D-86 distillation curves of ERBS-3, ERBS-3 blends, and blending stock.

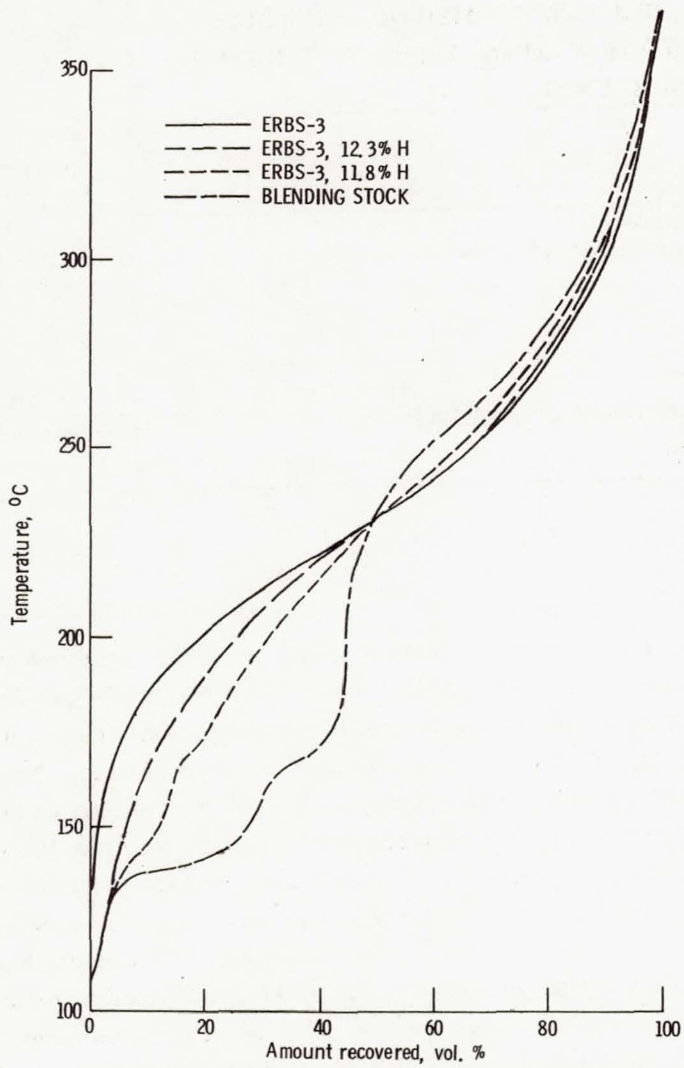

Figure 2. - ASTM D-2887 simulated distillation of ERBS-3, ERBS-3 blends, and blending stock.

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16. Abstract

Characterization data and comparisons of this data are presented for three individual lots of a research test fuel designated as an Experimental Referee Broadened-Specification (ERBS) aviation turbine fuel. This research fuel, which is a blend of kerosine and hydrotreated catalytic gas oil, is a representation of a kerojet fuel with broadened properties. To lower the hydrogen content of the ERBS fuel, a blending stock, composed of xylene bottoms and hydrotreated catalytic gas oil, was developed and employed to produce two different ERBS fuel blends. The ERBS fuel blends and the blending stock have also been characterized and the results for the blends are compared to those of the original ERBS fuel. The characterization results indicate that with the exception of the freezing point for ERBS lot 2, which was slightly high, the three lots, produced over a 2 year period, met all general fuel requirements. However, although the properties of the fuels were found to be fairly consistent, there were differences in composition. Similarly, all major requirements for the ERBS fuel blends were met or closely approached, and the properties of the blended fuels have been found to generally reflect those expected for the proportions of ERBS fuel and blending stock used in their production.

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